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POWER SYSTEMS DESIGN

IEEE Std 3001.8™-2013

IEEE Recommended Practice for the Instrumentation and Metering of Industrial and Commercial Power Systems

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IEEE Recommended Practice for the Instrumentation and Metering of Industrial and Commercial Power Systems

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Participants

The members of the P3001.8 Working Group include:

James Harvey, *Chair*

Gary Fox
Dave Korpess
William Moylan
Dave Wheeler

At the time this IEEE recommended practice was completed, the Power System Design Working Group had the following membership:

Peter Sutherland, *Chair*

Tom Baldwin
Kurt Clemente
Alireza Daneshpooy
Gary Fox
Russell Gentile
Manjinder Gill
Alok Gupta
James Harvey
Adrienne Hendrickson
Barry Hornberger
John Kay
Tanuj Khandelwal
Dave Korpess
Wei-Jen Lee
David Mills
Daniel Neeser
Lorraine Padden
Dev Paul
Abraham Pichardo
Louie Powell
Kent Sayler
Shelli Sedlak
James Smith
Jerry Smith
Sonny Sungupta
David Tepen
Steven Townsend

The following members of the individual balloting committee voted on this recommended practice. Balloters may have voted for approval, disapproval, or abstention.

William Ackerman
Mark Bowman
Frederick Brockhurst
Chris Brooks
William Byrd
Kurt Clemente
Carey Cook
Alireza Daneshpooy
Douglas Dorr
Neal Dowling
Donald Dunn
Gary Fox
Manjinder Gill
Randall Groves
Robert Hoerauf
Gael Kennedy
Yuri Khersonsky
Jim Kulchisky
Saumen Kundu
Wei-Jen Lee
Greg Luri
Daniel Neeser
Dennis Neitzel
Lorraine Padden
Louie Powell
Charles Rogers
Benjamin Rolfe
Bartien Sayogo
Robert Schuerger
Gil Shultz
James Smith
Jerry Smith
Peter Sutherland
Michael Swearingen
David Tepen
Marcelo Valdes
Tamatha Womack

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Wael William Diab
Stephen Dukes
Jean-Philippe Faure
Alexander Gelman
Mark Halpin
Gary Hoffman
Paul Houzé
Jim Hughes

Introduction

This introduction is not part of IEEE Std 3001.8-2013, IEEE Recommended Practice for the Instrumentation and Metering of Industrial and Commercial Power Systems.

IEEE 3000 Standards Collection™

This recommended practice was developed by the Technical Books Coordinating Committee of the Industrial and Commercial Power Systems Department of the Industry Applications Society as part of a project to repackage the popular IEEE Color Books®. The goal of this project is to speed up the revision process, eliminate duplicate material, and facilitate use of modern publishing and distribution technologies.

When this project is completed, the technical material in the thirteen IEEE Color Books will be included in a series of new standards—the most significant of which will be a new standard, IEEE Std 3000™, IEEE Recommended Practice for the Engineering of Industrial and Commercial Power Systems. The new standard will cover the fundamentals of planning, design, analysis, construction, installation, startup, operation, and maintenance of electrical systems in industrial and commercial facilities. Approximately 60 additional dot standards, organized into the following categories, will provide in-depth treatment of many of the topics introduced by IEEE Std 3000™:

- Power Systems Design (3001 series)
- Power Systems Analysis (3002 series)
- Power Systems Grounding (3003 series)
- Protection and Coordination (3004 series)
- Emergency, Standby Power, and Energy Management Systems (3005 series)
- Power Systems Reliability (3006 series)
- Power Systems Maintenance, Operations, and Safety (3007 series)

In many cases, the material in a dot standard comes from a particular chapter of a particular IEEE Color Book. In other cases, material from several IEEE Color Books has been combined into a new dot standard.

The material in this recommended practice largely comes from IEEE Std 141™ (*IEEE Red Book™*) and IEEE Std 241™ (*IEEE Gray Book™*).

IEEE Std 3001.8™

This recommended practice covers the instrumentation and metering of industrial and commercial power systems. It describes the importance of metering to achieve a successful energy management process, as well as considerations that must be made when applying the latest metering technology.

Contents

IEEE Recommended Practice for the Instrumentation and Metering of Industrial and Commercial Power Systems

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1. Overview

1.1 Scope

This recommended practice covers the instrumentation and metering (I&M) of industrial and commercial power systems. It describes the importance of metering to achieve a successful energy management process as well as considerations that must be made when applying the latest metering technology.

1.2 General

I&M is essential to satisfactory operation, monitoring, and trouble shooting of the electrical power distribution system serving any facility. Metering needs are now being driven by existing and new regulatory requirements relating to energy use and energy efficiency.

The specific requirements and complexity of the appropriate I&M for any facility, however, is highly dependent on the size and complexity of the facility. It is also dependent on economic factors related not

only to the first costs for installing the I&M; but more importantly upon the costs of downtime when the facility has a loss of power.

Good I&M provide the data needed to understand how the facility is using its electrical energy. This same information is also useful for controlling energy use (and associated costs) in the facility, determining the power quality present, and assisting in the determination of the causes of on-going electrical problems, power anomalies, and/or power outages.

2. Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.[1]

instrument: An instrument is defined as a device for measuring the value of the quantity under observation. This value is not reflective of, or related to, any other electrical characteristic of the power system. (Said another way, a volt-meter reading is not in any direct way affected by other variables in the power system such as current or power factor.) Instruments may be either indicating type or recording type. As used in this document, an indicating instrument means the value can be read for any given instant, but there is no method for knowing any of the prior values. Recording instruments, on the other hand, allow one to learn the instantaneous value and the prior values of the variable. Common recording methods include digital memory within the instrument itself, transmission of the values to remote computers via a communication link, and/or paper charts.

meter: A meter is defined as a device that can measure and register the integral of a quantity over an interval of time. Integral in this sense means that multiple values of the power system quantity are used to register the value being monitored. The kilowatt-hour meter is the most common type of meter. Such a meter integrates the instantaneous values of voltage, current, and power factor to calculate the kilowatts being consumed, and that value over time results in kilowatt-hour consumption values. (It should be noted that many kilowatt-hour meters are often configured to also register the maximum demand values seen by the meter since its last reset.)

NOTE—In common usage, instrument and meter are often used interchangeably. For example, the term meter is commonly used with other words, such as VAR-meter, voltmeter, and frequency meter, even though these devices are technically instruments.[2]

3. Examples of service instrumentation and metering

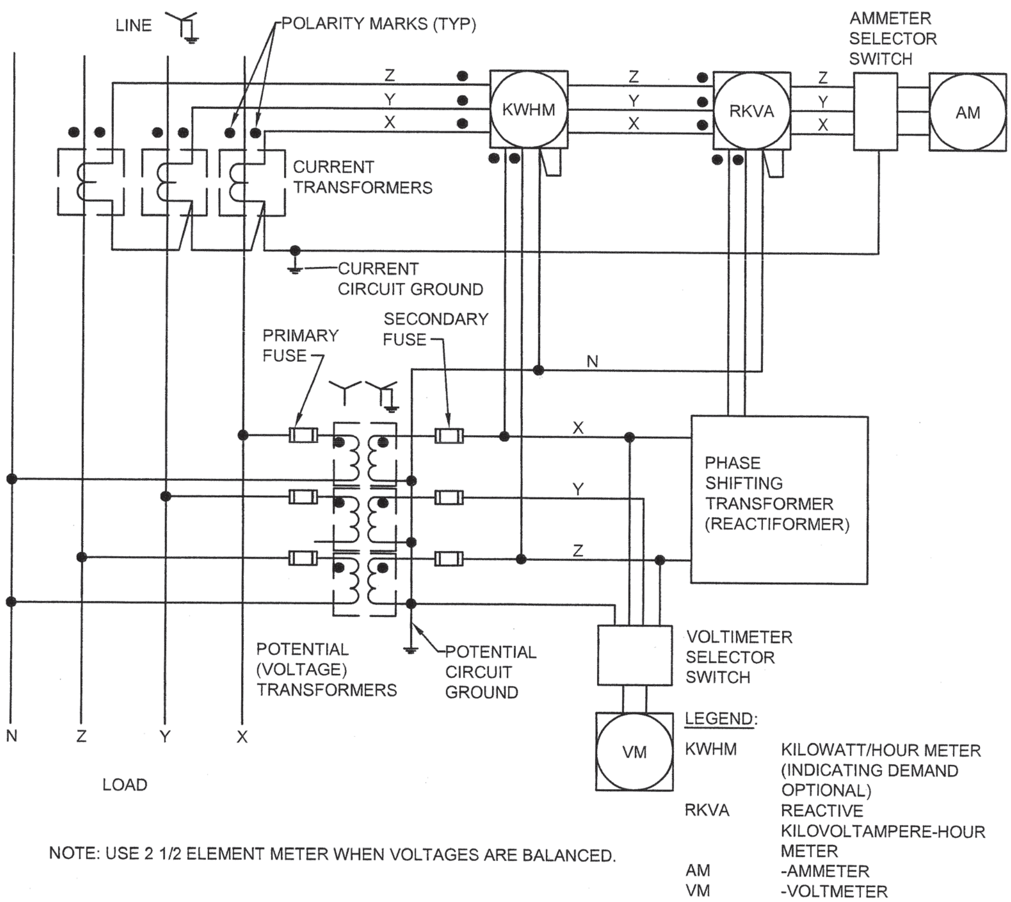
Below are several examples of the metering that may be installed on an industrial or commercial service entrance.

NOTE—These examples do not, however, necessarily represent the metering schemes used by the utilities for billing. The utilities often utilize meter types that can handle currents of 200 A, or more, without need for current transformers.

[1] *IEEE Standards Dictionary Online* subscription is available at: http://www.ieee.org/portal/innovate/products/standard/standards_dictionary.html.
[2] Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

3.1 Services that are 3-phase, 4-wire with high current levels and higher voltages

Figure 1 is for a higher current and higher voltage, three phase, and 4-wire services. In this sense, higher currents mean currents above 200 A. In like manner higher voltage means above 208 V, since most instruments and meters cannot handle more than 120 V in their wye connected voltage coils.



(See 6.1.3 for more information on 2-1/2 stator meters)

Figure 1—3-phase, 4-wire, high current and higher voltage services

3.2 Services that are 3-phase, 3-wire, with high current levels and higher voltages

Figure 2 is also for higher currents and higher voltages as noted above, except that it is for a three-wire system. The definitions for high current and high voltage are similar to the above. Also, while only two current transformers are shown in this example, it is not uncommon to also see applications where three current transformers might be used.

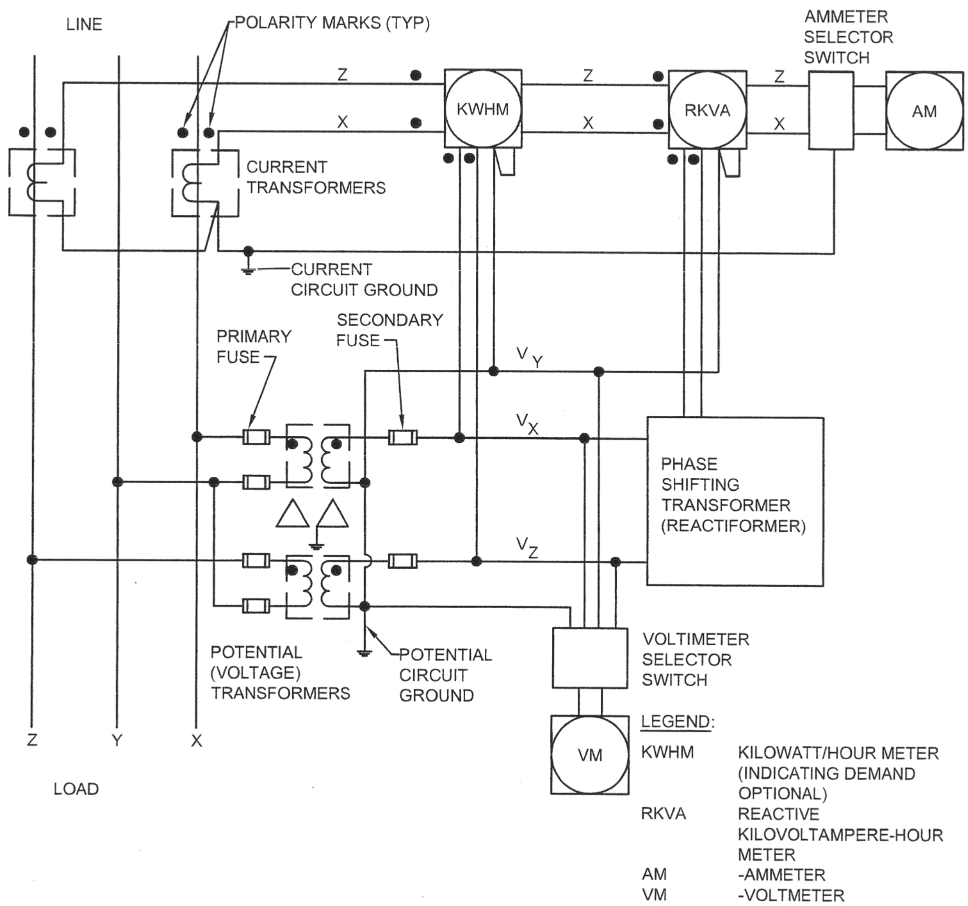


Figure 2—3-phase, 3-wire, high current and higher voltage services

3.3 Primary voltage substation—service is above 600 V

Figure 3 is for an application of a facility receiving its power from the utility at voltages above 600 V. These services typically have power demands of over 1000 kW. There are two special notes about this figure. First, it is shown in a single-line line format instead of the three-line format used in the above two examples. The three-wire format was deemed too complex for this application. Second, since the facility is such a high power user and has an emergency generator, some detail of the in-the-plant configuration is being given.

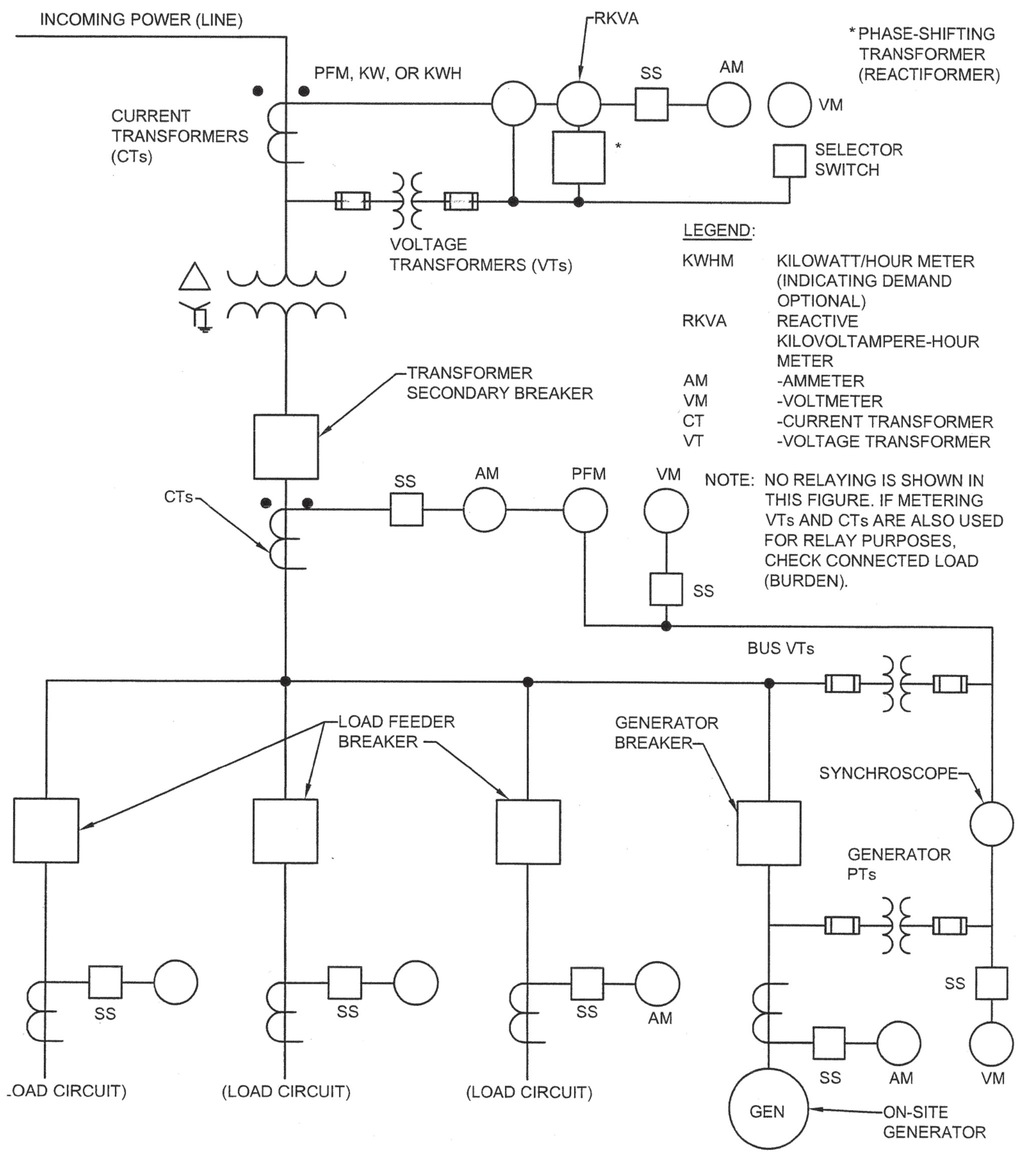


Figure 3—Primary voltage substation sample metering layout

3.4 Issues affecting the above noted examples

Digital metering systems that are currently available typically combine both the instrument and meter functionalities into packages that are much smaller and more versatile. For this reason alone, they are becoming the preferred type of instrumentation and metering used in many venues.

Digital meters also offer more computational and data storage capabilities than users might reasonably expect from discrete and dedicated components. They can also be programmed with instrument transformer ratio ratings, demand intervals, minimum/maximum logs, and alarm set points. Many such devices also offer communication ports for their integration into industrial plant supervisory systems for detailed monitoring and analysis.

3.5 Other configuration and application issues

AC and dc instruments and meters should not be used interchangeably due to the differences in how they are constructed. In general, dc instruments and meters cannot be used on ac circuits. However, some ac instruments and meters, depending on their construction, may be suitable for dc purposes. The manufacturer's instructions, as well as the information on the nameplate of the device, should clearly indicate the acceptable usages.

Instrument and meter users should be very aware that the algorithms used in many ac devices provide accurate results only when a pure ac sine wave is being measured. Given the high percentage of non-linear (high harmonic) loads found in today's facilities, a pure sign wave may not be present. Reading accuracy will therefore be significantly impaired, from the published meter accuracy, when non-linear loads are present.

As noted in IEEE Std 1100™ (*IEEE Emerald Book™*)[3,4] [B16][5] Table 5.2 (also in 8.1), the readings of some devices may be as low as 60% of actual rms (root mean square) value, to a high of 184% of the actual rms—with the inaccuracy being very dependent on the variance of the waveform from that of a pure sign wave. In that same table, it is noted that only devices using a true rms algorithm provide rated good accuracy for all waveforms. The accuracy variations in non-rms devices can be great enough that the user may reach incorrect conclusions from the readings. Users should, therefore, be aware of the limitations of their equipment and should select instruments and meters appropriate for the application.

4. Basic objectives

Instruments and meters are used in facilities for such purposes as operating, monitoring, billing, accounting, planning, assuring safe operations, conserving energy, and maintaining equipment. They provide information such as the magnitude of an electrical load, energy consumption, load characteristics, load factor, power factor, and voltage.

Before being placed in service, the electrical equipment of a plant should undergo certain performance checks. These would include determining whether the voltages are correct, the insulation is in proper condition, and that connections have been properly made. After the equipment is in service, additional periodic checks are necessary to assure proper equipment operation or to locate problems.

Care should be taken to assure that instruments and meters are compatible to their application to prevent personal injury or damage to the instruments themselves. Care should also be taken to assure that items such as polarity, phase rotation, tap settings, and burdens are correct, all to ensure accurate readings. All instruments and meters should be checked and recalibrated periodically.

5. Instruments

There are two common classes of permanently mounted instruments—switchboard type and panel type. Both classes of instruments are single-range devices and are essential for the continuing operation and maintenance of any commercial or industrial facility.

It should be pointed out the definition of an instrument is a device that measures the value of a given quantity under observation (e.g., amperes or volts). The definition of a meter is a device that measures and

[3] The IEEE standards or products referred to in this document are trademarks of The Institute of Electrical and Electronics Engineers, Inc.
[4] IEEE publications are available from The Institute of Electrical and Electronics Engineers, 445 Hoes Lane, Piscataway, NJ 08854, USA (http://standards.ieee.org/).
[5] The numbers in brackets correspond to those of the bibliography in Annex A.

registers the integral of a quantity over a period of time (i.e., kilowatt-hours or reactive kilovolt ampere-hours). Common usage, however, often applies the name meter to what may actually be an instrument. Many of the instruments described below reflect the common usage of these terms.

The current coils and/or inputs of most instruments are rated 5 A, while their potential coils are typically rated 120 V phase-to-ground (or phase-to-phase). Whenever the system's maximum currents and/or the voltages of the monitored system exceed these ratings, current and potential (voltage) transformers are required. The use and application of these devices are described later.

5.1 Size and accuracy of switchboard and panel mounted instruments

In general, switchboard instruments are larger and have longer scale lengths (or digital displays with more digits) than an equivalent panel instrument. For example, a switchboard analog ammeter might be 10cm^2 to 12.5 cm^2 (4 in^2 to 5 in^2) with a scale length of 15 cm (6 in); an equivalent panel ammeter might have a diameter of 5 cm to 7.5 cm (2 in to 3 in) and a scale length of 4 cm (1.5 in). As a general rule for analog instruments, the longer the scale length is, the higher its full-scale accuracy.

It should be noted that accuracy of all analog meters at low scale readings (less than 20% of full-scale reading) are significantly less than the full-scale accuracies. In a similar manner, digital instruments often have accuracy ratings as a percentage of the reading, plus or minus one or more digits. Some of the more common instruments are discussed below. (See also ANSI C39.1 [B11] for standard sizes, scales, and accuracies.)

The full-scale reading for an analog instrument equals, or is a function of, the primary rating of the installed instrument transformers. For example, a full-scale reading of an ammeter connected with a 1200:5 current transformer will be 1200 A. If the normal load current, however, is 400 A, the readings may be less accurate and may be difficult to read. In such cases, it might be better to specify a 2.5 A instrument or a 600:5 CT for higher accuracy and ease of reading.

Digital instruments normally permit programming of the instrument transformer ratio rating. This offers users greater flexibility when specifying instrument transformer ratios and instrument full-scale ratings.

While it should never be an issue with switchboard and panel meters, one should always be sure that the devices reflect rms values. Devices reading peak (and not rms) values will give misleading results. Since most facilities today have a significant portion of non-linear loads, the differences between rms readings and peak readings are often significant. For devices monitoring dc systems, this is normally not an issue.

5.2 Ammeters

Ammeters are used to measure the current that flows in a circuit. If the current is less than 5 A, an ammeter may be series connected in the circuit to be measured. If the current is greater than 5 A, the ammeter typically measures the circuit indirectly via a current transformer or a shunt.

Selector switches (SS) are often installed so that one ammeter may be connected to any of the phases and switched between phases. Often these selector switches also have an off position.

5.3 Voltmeters

Voltmeters are used to measure the potential difference between conductors or terminals. A voltmeter is connected directly across the points between which the potential difference is to be measured. Potential

(voltage) transformers are generally required when more than 120 V is monitored. Selector switches are often installed so that one voltmeter may be connected between any two phases and phase-to-ground, or turned off.

5.4 Watt-meter

By measuring and sampling the rms voltage(s), the rms current(s), and the displacement angle (actually the cosine of the angle) between the voltage wave and the current wave, a watt-meter measures the magnitude of electric power being delivered to all of the loads on the circuit being monitored. Proper application of this instrument requires care when connecting so that correct polarity and phasing of both the voltage connections and current connections is achieved. Scale factors for watt-meters typically indicate kilowatts (kW) or megawatts (MW).

5.5 VAR-meter

By measuring and sampling the rms voltage(s), the rms current(s), and the displacement angle (actually the sine of the angle) between the voltage wave and the current wave, a VAR-meter measures the reactive power being delivered to all of the loads on the circuit being monitored. VAR-meters usually have the zero point at the center of the scale since reactive power may be leading or lagging. The VAR-meter has an advantage over a power-factor meter in that the scale is linear; thus small variations in reactive power can be read. Scale factors for VAR-meters typically indicate kilovars (kVAR) or megavars (mVAR).

5.6 Power-factor meter

By measuring the angle (actually the cosine of the angle) between the voltage wave and the current wave, a power-factor meter indicates the power factor of the load being monitored. The meter typically indicates unity power factor at center scale, leading power factor to the left of center, and lagging power factor to the right of center.

Power-factor meters are accurate only when adequately loaded. When accuracy is desired throughout the load range, a watt-meter and a VAR-meter should be used in combination. Also, many power-factor meters can usually only monitor the power factor of one phase at a time. This often leads to erroneous conclusions if the phase loads are not similar and if just one reading is taken.

NOTE—The proper selection of a power-factor meter or other instrument intended to monitor multiphase systems depends on the system to be monitored; for example, 3-phase, 3-wire; or 3- phase, 4-wire wye; or 3-phase, 4-wire delta, etc.

5.7 Frequency meter

The frequency of an ac power supply can be measured directly by a frequency meter. The frequency meter measures the zero crossings of the waveform over time and computes the frequency based on the number of zero crossings per second divided by two.

5.8 Synchroscope

A synchroscope shows the phase-angle difference between two systems and is used wherever two sources (generators or systems) are to be connected in parallel. (A typical example might be where a generator is to

be connected to and/or operated in parallel with the utility system.) A synchroscope has the appearance of other switchboard meters, except that in a synchroscope, the pointer is free to revolve 360° in either direction.

When the frequency of the system that is being synchronized, typically the smaller system (generator), is too low as compared to the larger source (utility), the pointer rotates in one direction. When it is too high, the pointer rotates in the opposite direction. When the pointer is rotating slowly, the frequencies are essentially equal.

When voltmeters indicate that the voltages are equal, and the pointer of the synchroscope indicates a zero angular difference (pointer is pointing directly up), the circuits are in phase, and the systems may be safely paralleled by closing the tie-breaker.

5.9 Elapsed time meter and operations counter

Elapsed time meters have a small, synchronous motor that drives cyclometer dials or a digital display. The dials register the cumulative amount of time a circuit or apparatus has been in operation. A device with a similar purpose is an operation counter which totalizes the number of times the monitored equipment has operated. In either case, this information allows for economic planning of needed preventive maintenance on the monitored equipment.

6. Meters

6.1 Kilowatt-hour meters

A kilowatt-hour meter measures the amount of energy being consumed by a load passing the point where the meter is applied.

The formerly common analog ac kilowatt-hour meters use an induction-disk type of mechanism. The disk revolves at a speed proportional to the rate at which energy passes through the point being metered. The metered kilowatt-hours consumed are indicated on a set of dials driven by the revolving disk through a gear train.

The now common solid-state kilowatt-hour meters use a wide variety of electronic methods to determine the amount energy being consumed by the load. Many solid-state meters also record other quantities, such as kilovars, kilowatts, volts, amperes, and power factor.

An analog kilowatt-hour meter may be used to calculate the kilowatt power being used by a load at any given time. To calculate the then present demand, count the seconds for a given number of revolutions of the disk, and use the following formula. Select a number of revolutions such that the timing of the test is at least 30 s. The longer the test time, the better the accuracy will be. For example, a 1 s error in a 10 s reading results in a 10% error, while that same 1 s error in a 30 s reading results in a 3.33% error.

$$\text{kW} = (3.6 \times K_h \times R \times M) / s$$

kW is kilowatts.

K_h is the constant of the meter and can almost always be found on the meter nameplate.

R is the number of revolutions timed.

M is the multiplier and can almost always be found on the meter. If the multiplier is not noted on the nameplate, however, it can be calculated as shown:

1) If the meter has no current transformers (CTs), or potential transformers (PTs), the multiplier would typically be 1.

2) The multiplier for a meter with just CTs can be calculated as follows. For example, a meter with a 400:5 (80:1) ratio CTs would have a multiplier of 80.

3) If this same meter also had PTs of 4800:120 (40:1), its multiplier would be of 3200. Eighty from the CT ratio multiplied by 40 from the PT ratio.

Solid-state meters allow the user to program the CT ratio and the PT ratio (multiplier) when these are present. With the ratios programmed, these meters will then display actual kilowatts, kilowatt-hours and often many other variables directly on the register.

6.1.1 Kilowatt-hour meters classes

Below is a list of the common classes of kilowatt-hour meters along with the maximum current each can safely monitor. (These maximum current ratings are typically noted on the nameplate of the meter by the manufacturer.) These classes of meters are used most frequently by utilities but are also used within commercial and industrial facilities when the system to be metered is appropriate for their use.

Class 10	10 A
Class 20	20 A
Class 100	100 A
Class 200	200 A
Class 320	320 A

High-current services would require a Class 10 or Class 20 meter employed with CTs. For example, a 1000 A service would use 1000:5 (200:1 ratio) CTs and a Class 10 (or Class 20) meter.

6.1.2 Kilowatt-hour voltage ratings

Kilowatt-hour meters typically are rated for either 120 V or 240 V potential coils. Higher voltage applications require the use of voltage transformers.

6.1.3 Kilowatt-hour selection and stator configurations

The following kilowatt-hour meter application data can be used only as a general guideline. The numbers of phases, the number of wires (e.g., single-phase two or three-wire, three-phase 4-wire, three-phase three-wire, etc.), the amount of current, anticipated phase-to-phase current balance, and power-factor balance all have an effect on the number of stators (or coils) the kilowatt-hour meter should have. An unbalanced condition exists if the phase-to-phase differences in load current (over 10%), or load power-factor (less than 85%), or greater.

While the stator designation was originally applicable directly to analog meters, the industry in general uses a similar characterization for digital meters.

The data in Table 1 defines the number of stators and, if required by the service voltage or load size, the number of CTs and PTs required to properly meter common services.

Table 1—Metering and instrument transformer requirements

Service voltage	Stators	CT Note 1	PT Note 2	Assumed load characteristic
1-phase, 2-wire	1	1	1	
1-phase, 3-wire	1	2	1	
1-phase, 3-wire	2	2	2	
1-phase, 3-wire (wye)	2	2	2	
3-phase, 3-wire (delta)	2	2	2	
3-phase, 4-wire (wye)	$2^1/_2$	3	2	balanced conditions
3-phase, 4-wire (wye)	3	3	3	
3-phase, 4-wire (delta)	3	3	3	
3-phase, 4-wire (delta)	2	3	2	balanced mid-tap voltage

NOTE 1—If maximum current of service being metered is less than 320 A, use Class 100, Class 200, or Class 320 as appropriate. If maximum current is above 320 A, CTs will be needed. In either case, the meter would be Class 10, with the number of CTs as shown. Typically the secondary current rating is 5 A.

NOTE 2—If voltage applied to meter is above 240 V, PTs will be required, with the number as shown. Typically the secondary voltage rating is 120 V.

Other factors used in selecting kilowatt-hour meters include the following:

— Type of mountings: socket, bottom-connected, switchboard
— Voltage: 120 V, 240 V, 240 V/120 V, etc.
— Register: clock, cyclometer (like an odometer), digital
— Type of load current bypass: automatic, manual

6.1.4 Using caution when selecting and connecting kilowatt-hour meters

Even with the above table as a guide, a person not well versed in the intricacies of metering may err either in selecting the proper kilowatt-hour meter type and/or in connecting the meter. This is especially true when instrument transformers are required. If there is any doubt, consult a metering specialist. (Field experience of meter certifiers has shown that often as many as one-third, or more, of the meters inspected are either incorrectly specified, and/or are improperly connected.) An excellent reference on all aspects of kilowatt-hour meters is the *Handbook for Electricity Metering* [B13].

The above noted difficulty in selecting and wiring kilowatt-hour meters also applies to the selection and wiring of kilovar-hour meters and demand meters.

6.2 Kilovar-hour meters

A kilovar-hour meter measures the reactive energy consumed by a load by continuously sampling the rms voltage(s), the rms current(s), and the displacement angle (actually the sine of the angle) between the voltage wave and the current wave, over time, to measure the reactive power being delivered to the loads being metered. The internal mechanisms of the kilovar-hour meter are identical to those of a kilowatt-hour

meter. However, the potential applied to this meter is shifted 90 electrical degrees. A standard kilowatt-hour meter and a phase-shifting transformer can be connected to function as a kilovar-hour meter.

To calculate kilovar demand, apply the timing formula defined in 6.1. Data from a kilovar-hour meter and a kilowatt-hour meter may be used to calculate power-factor percentage using the following formula:

$$\text{Power Factor} = \cos\left(\operatorname{atan}\left(\frac{\text{kvarh}}{\text{kwh}}\right)\right) 100\% \qquad \text{(Power factor in percent)}$$

Most kilovar-hour meters have a ratchet-type assembly to prevent them from running backward. For this reason, depending upon the connection, they can record only lagging or leading kilovar-hours. If digital meters are being used, however, many of these can concurrently display both leading and lagging values.

6.3 Demand meters

Demand meters register the average power demand during a specified time interval. They record the demand for each interval or indicate the maximum demand since the meter was last reset. Demand meters are normally an attachment or added feature to kilowatt-hour meters.

A lagged demand meter indicates demand by a thermally driven pointer on a scale. The internal thermal characteristics of the meter determine the time interval. A red indicating demand pointer shows the load through the course of the high-load period. This pointer moves a black maximum pointer upscale with it. The black pointer will stay at the maximum value until the meter is read and reset. The demand of a constant load is reasonably approximated by this type of meter after two time intervals.

A demand meter records the average power during a specific interval. A kilowatt-hour meter equipped with a contactor device provides information on energy usage, with each impulse (contact closure) representing the usage of a specified amount of energy. The recording demand meter records the total number of impulses received during each time interval. The record may be on printed paper tape, a chart, punched tape, magnetic tape, or a computer memory system.

It is good to compare the readings of the facility's demand meter with that of the utility's demand to ensure that the two match. If they do not match, have the connections and settings of the facility's demand meter carefully checked. If the difference continues after making the needed corrections, if any, contact the utility. It is possible the error may be in their demand meter, and this likely affects the cost of the purchased energy.

7. Portable instruments

WARNING

Portable meters should always be used with extreme care. In many situations only qualified personnel, as defined by NFPA 70E, are permitted to use portable instruments and/or to take the readings. Under the NFPA 70E definition, qualified personnel would typically include journeyman electricians or master electricians who are wearing the appropriate personal protective equipment (PPE).

A portable instrument may have the same functions as a switchboard instrument, but it is typically installed in a protective case. Ordinarily, portable instruments have many ranges and functions. They are useful for special tests or for augmenting other measuring instruments mounted on a switchboard. Portable CTs

and PTs are also available for situations when the range of the portable instrument is not sufficient for the values to be measured. They can thus provide flexible instrumentation for various conditions.

Users of portable instruments should be aware of the maximum voltage, current, and other ratings of the instrument. Attempting to use an instrument beyond its capabilities may cause serious injury to the user. Care should be exercised to be sure the test leads are properly connected before applying the test probes to the energized circuit. Measuring voltage with a multimeter connected for current could result in a damaged meter, an unexpected process shutdown, or even injury.

7.1 Clamp-on ammeters

A clamp-on ammeter uses a split-core CT to encircle a conductor and determine the amount of ac current flowing. It usually has several current ranges. Hall-effect clamp-on CTs will read dc currents in addition to ac currents.

7.2 Volt-ohmmeter (VOM), digital multimeter (DMM)

This instrument can indicate a wide range of voltages, resistances (in ohms), and currents (in milliamperes). It is particularly useful for investigating circuit problems. Several of these instruments record higher currents using portable clamp-on CTs with typical ratios of 1000:1 in conjunction with a milliampere scale on the VOM.

8. Recording instruments

Many direct-reading, indicating instruments are available as recording or curve-drawing instruments for portable or switchboard use. Older recording methods use strip or circular charts. The record may be continuous, or readings can be taken at regular intervals. The chart moves at a constant speed by a spring or electrical clock. Recording instruments have special design problems that indicating instruments do not have. One problem is the need to overcome pen friction without impairing the accuracy of the recording.

Modern instruments and meters are available with electronic recording capability, both of which can be read by other computers. Be sure to select instruments that have sufficient memory to hold all of the data, without loss of data, given the application and length of metering. These instruments permit more data storage and thereby allow additional calculations and analysis. They greatly reduce the maintenance and service required.

8.1 Power quality analyzers

Power quality analyzers are a class of specialized recording instrumentation designed to record voltage and/or current disturbances in power systems. Some also record temperature, humidity, radiated radio-frequency energy, sequence of events, and other useful data. They have adjustable disturbance thresholds that often include fast voltage transients usually much less than 1 ms., wave-shape disturbances, momentary changes in average voltage lasting between about 1 cycle and 2 s, long-term changes in average voltage, and harmonic distortion. Disturbance analyzers report data using non-volatile memory and can output the readings to CD, DVD, or over a network connection. Newer models have the ability to interface directly with personal computers.

Users should be careful when interpreting the readings from disturbance analyzers due to their unique properties. For example, most waveform disturbance analyzers will not record or display voltage transients

in amplitude that is below the threshold setting. The display may show voltage transients above the threshold but may not display voltage transients less than the threshold even though they occurred in the same event.

Power quality, and the I&M needed to monitor and analyze it, is a detailed subject unto itself.

8.2 Load profile recorders

Load profile recorders are microprocessor controlled instruments that record voltage, current, watts, vars, power factor, volt-amperes, and harmonic power levels in a power system. Demand intervals, min/max readings, and other reporting characteristics are programmable. These recorders often can interface with personal computers in manners similar to disturbance analyzers.

8.3 Computer data acquisition systems

Several add-on circuit modules are often available that operate with custom software to convert personal computers into powerful data acquisition systems and data loggers. These systems typically offer many channels of data that are fed into analog and digital converters. The current converters typically have 12 bit, 16 bit, or even higher bit resolution for very accurate recordings so long as a large portion of the dynamic range is used. These systems typically require signal conditioning amplifiers to provide voltage reduction and isolation and to prevent aliasing errors.

8.4 Oscillographs

An oscillograph is an instrument for observing and recording rapidly changing values of short duration, such as the waveform of alternating voltage, current, or power transients. They can easily portray and record sub-cyclic events such as inrushes, faults, and like occurrences. They are also useful in analyzing harmonic current and harmonic potential problems and issues. With power system applications, a broad frequency bandwidth into the megahertz ranges is typically not needed. Oscillographs are, however, available for a very wide range of frequencies when applied with instrument transformers with sufficient frequency responses.

9. Auxiliary devices

9.1 Introduction

The following are points needing to be addressed when selecting auxiliary devices for metering purposes.

The two major types of auxiliary devices used in ac meter applications are CTs and PTs. For more in-depth coverage of the specifics of CTs and PTs, refer to IEEE Std 3004.1™ [B17], which is dedicated in large part to these subjects.

9.2 Current transformers

CTs insulate the instrument circuit from the primary voltage and produce an output current proportional to the input current. Care should be taken to ensure the CT is insulated for the full system voltage. For example, CTs in the 600 V class are used for 480 V systems, and CTs in the 15 kV class would be used for 13.8 kV systems.

CTs also reduce current through the connected instruments to values within the rating of the instrument elements, typically 5 A. The recommended ratio rating choice, therefore, should supply about 5 A to the instruments when the monitored circuit load current is equal to the highest anticipated load under normal conditions.

Note that the actual loading seen/present on any given system or piece of equipment is often (sometimes significantly) less than the rating of the bus and/or the main breaker. When this difference is significant, the CT selected may result in a lower degree of accuracy.

A CT can generate a dangerously high secondary voltage when the secondary current circuit is open while primary current is flowing. Therefore, a shorting bar, test switch, or current jack should be provided to short-circuit the transformer secondary when the connected instrument is being tested. (Refer to the National Electrical Safety Code® (NESC®)[6] [B1], Section 15 for more information.) Providing a test switch or current jack allows easy connection of portable meters.

Note also that CTs should have a secondary circuit ground at one point where they are required to be grounded. The National Electrical Code® (NEC®)[7] [B19], Section 250, Part IX specifies minimum grounding requirements for instrument transformers. The ground will establish a firm ground reference point and will restrict the buildup of static voltages caused by the high-voltage conductor(s).

9.3 Potential (voltage) transformers

When the potential of the service being metered is above 120 V/240 V, PTs are typically required. PTs are used to reduce the service voltage to the level that the meter or instrument can utilize. Switches should be provided in the secondary circuit of the PT to disconnect the instrument for testing.

The secondary circuit of a voltage transformer should be grounded. The NEC, Section 250, Part IX specifies minimum grounding requirements for instrument transformers. In most industrial applications, the primary and secondary circuits are fused. Furthermore, voltage transformers should be identified on one-line diagrams as an isolation, or tagging, point if the secondary may be energized while the primary source is disconnected.

9.4 Shunts

For direct current measurements of current or energy, shunts are often used to carry the main current to be measured. Ordinarily, the leads should be calibrated with the shunt with which they are to be used. The dc ammeter actually measures the millivolt drop across its shunt and is calibrated in terms of the current rating of its associated shunt.

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[6] National Electrical Safety Code and NESC are both registered trademarks and service marks of The Institute of Electrical and Electronics Engineers, Inc.
[7] National Electrical Code, NEC, NFPA 70 are registered trademarks of the National Fire Protection Association, Inc.

9.5 Transducers

A transducer is a device that is used to transform one or more analog inputs into another analog value more suitable for usage in instrumentation. The output is related to the input(s) in a prescribed relationship. They are commonly used for remote metering or to provide analog data to programmable logic controllers and computers. They generally isolate the current and voltage transformer secondary circuits from the wiring to the remote location. Many transducers output a current in milliamperes that is proportional to the measured quantity. This allows the signals to be transmitted over long distances with small gauge wires.

Some transducers can now be replaced with digital multifunction power monitors that can communicate all measured parameters via one communication cable to a remote monitor or data acquisition device. These are similar to multifunction digital instruments/meters, but do not include a local display or key pad.

10. Instruments and meters commonly selected for various types of power services and applications

The following combinations of instruments and meters are commonly used in industrial and larger commercial facilities.

Also, as previously noted, some types of electronic metering equipment as well as some electronic overcurrent protection devices often combine many of these features in one package.

10.1 Equipment above 600 V (medium voltage)

The following I&M is recommended for medium voltage (typically 1000 V to 15 000 V) switchgear that serves secondary voltage (600 V class) substations, medium voltage generators, and motor loads. These recommendations are justified in most instances given the higher power levels being handled, the criticality of the monitored equipment, and loads.

NOTE—The metering required by the utility company is not reflected here. These would be additional.

a) Utility supply and/or main feeder positions: voltmeter, ammeter, kilowatt meter, kilovar meter or power-factor meter, kilowatt-hour meter, demand meter (optional), and test block for portable instruments.

b) Plant feeders: ammeter, kilowatt-hour meter (demand attachment optional), test block for portable instruments (optional).

c) Generators: voltmeter, ammeter, kilowatt-hour meter, kilovar meter or power-factor meter (optional), synchroscope, frequency meter (optional), recording ammeter and voltmeter (optional), test block for portable instruments (optional).

d) Synchronous motors: ac and dc voltmeters (optional), ac and dc ammeters, kilowatt meter (optional), kilovar meter or power-factor meter (optional), kilowatt-hour meter (optional), elapsed-time meter (optional).

e) Large induction motors: ammeter, voltmeter (optional), kilowatt-hour meter (optional), and elapsed-time meter (optional).

10.2 Equipment 600 V and lower

Services of 600 V and lower are generally serving lower power levels and, in some cases, lower priority loads—at least as compared to those typically carried by medium-voltage equipment. The added cost of the

full I&M may be justified only when the potential saving in operations or maintenance can justify the full expense. If full (or any) permanent I&M is not used, operational testing needs to be done periodically with portable instruments to monitor operational patterns. To allow this testing, test blocks should be provided where portable instruments can be connected easily and safely.

NOTE—The metering required by the utility company is not reflected below. These would be additional.

a) Utility supply and main feeder positions: voltmeter, ammeter, kilowatt meter, kilowatt-hour, meter, kilovar meter or power-factor meter (optional), demand meter (optional), test block for portable instruments (optional).

b) Plant feeders: ammeter, kilowatt-hour meter (optional), test block for portable instruments (optional).

c) Generators: voltmeter, ammeter, kilowatt-hour meter, kilovar meter or power-factor meter (optional), synchroscope, frequency meter, recording ammeter and voltmeter (optional).

d) Synchronous motors: ac and dc voltmeters (optional), ac and dc ammeters, kilowatt meter (optional), kilovar meter or power-factor meter (optional), kilowatt-hour meter (optional), elapsed-time meter (optional).

e) Large induction motors: ammeter, voltmeter (optional), kilowatt-hour meter (optional), and elapsed-time meter (optional).

Annex A

(informative)

Bibliography

Bibliographical references are resources that provide additional or helpful material but do not need to be understood or used to implement this standard. Reference to these resources is made for informational use only.

[B1] Accredited Standards Committee C2-2012, National Electrical Safety Code® (NESC®).[8]

[B2] ANSI C12.1, American National Standard Code for Electricity Metering.[9]

[B3] ANSI C12.4, American National Standard for Registers—Mechanical Demands.

[B4] ANSI C12.5, American National Standard for Thermal Demand Meters.

[B5] ANSI C12.6, American National Standard for Phase-shifting Devices Used in Metering, Marking and Arrangement of Terminals.

[B6] ANSI C12.7, American National Standard for Requirements for Watt-hour Meter Sockets.

[B7] ANSI C12.8, American National Standard for Test Blocks and Cabinets for Installation of Self-Contained Base Watt-hour Meters.

[B8] ANSI C12.9, American National Standard for Test Switches for Transformer-Rated Meters.

[B9] ANSI C12.10, American National Standard for Physical Aspects of Watt-hour Meters.

[B10] ANSI C12.11, American National Standard for Instrument Transformers for revenue Metering, 10 kV Bil through 350 kV.

[B11] ANSI C39.1, American National Standard Requirements for Electrical Analog Indicating Instruments.

[B12] *Electric Utility Engineering Reference Book, Volume 3: Distribution Systems,* Chapter 1 1H, Westinghouse Electric Corporation, Trafford, PA, 1965.

[B13] *Handbook for Electricity Metering,* Ninth Ed., Edison Electric Institute, Washington, DC, 1992.

[B14] IEEE Std 100™, IEEE Standard Dictionary of Electrical and Electronics Terms.

[B15] IEEE Std 242™, IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems (*IEEE Buff Book™*).

[B16] IEEE Std 1100™, IEEE Recommended Practice for Powering and Grounding Electronic Equipment (*IEEE Emerald Book™*).

[B17] IEEE Std 3004.1™, IEEE Recommended Practice for the Application of Instrument Transformers in Industrial and Commercial Power Systems.

[B18] IEEE Std C57.13™, IEEE Standard Requirements for Instrument Transformers.

[B19] NFPA 70, 2008 Edition, National Electrical Code® (NEC®).[10]

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[8] The NESC is available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, Piscataway, NJ 08854, USA (http://standards.ieee.org/).

[9] ANSI publications are available from the Sales Department, American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA (http://www.ansi.org/).

[10] The NEC is published by the National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02169, USA (http://www.nfpa.org/). Copies are also available from The Institute of Electrical and Electronics Engineers, 445 Hoes Lane, Piscataway, NJ 08854, USA (http://standards.ieee.org/).

[B20] Purkayastha, I., Savoie, P. J., "Effect of harmonics on power measurement," *Petroleum and Chemical Industry Conference,* Sept. 1989.